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seum of Natural History, but a use was also made of type material in other collections.

Osborn's idea in presenting the matter in this form is that "the permanent data of systematic paleontology are the *type specimens*, determinate or indeterminate, the *type locality*, the *type geologic level*. Descriptions, figures, opinions, inferences, phylogenetic and other speculations are subject always to the fallibility of human observation and interpretation." These ideas of course are fundamental and apply to other phases of paleontology than the systematic portion.

A full discussion of the "Genesis and Evolution of Single Dental Characters" is given with abundant illustrations. This is followed by a review of "Geologic Horizons and Life Zones" appropriately illustrated with maps and tables.

The systematic portion discusses one hundred and forty-six species distributed among ten genera. Each species is carefully discussed and the type material illustrated. On turning the pages one is struck by the fragmentary nature of many of the species—but this is the condition throughout all fossil vertebrate groups. To some of the species more information has been added since their description but many of them stand to-day as they were originally described. Many species are known from very complete material.

The contribution is one of which American paleontologists may well be proud. Its permanent character is the careful collection and assembling of data on all species of fossil horses known from the Oligocene to the Pliocene of North America. The magnitude of the task is almost appalling in the amount of detailed work involved. The author tells us that this is a portion of the work done in connection with his "Monograph of the Equidæ" on which he has been working for the last eighteen years. A portion of the present work is due to the collaboration of Dr. W. D. Matthew to whom the author gives full credit.

The high standard assumed by the publications of the American Museum of Natural History twenty-five years ago is maintained

in the present memoir. The typography and illustrations are excellent. ROY L. MOODIE

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## SPECIAL ARTICLES

### NOTE ON MEASURING THE RELATIVE RATES OF LIFE PROCESSES

THE development of quantitative methods in biology depends largely on finding means of measuring the speed of life processes. In most cases the absolute rate is of less importance than the relative rate (*e. g.*, the normal velocity compared with that observed under the influence of a reagent). Examination of the literature shows that the determination of relative rates is frequently made in a faulty manner, which could easily be avoided by a slight change of method.

We may illustrate this by supposing that the life process in question is a chemical one. The rate of a chemical reaction is expressed by its velocity constant. The simplest case is that in which a single substance, *A*, decomposes. The usual equation is<sup>1</sup>

$$K = \frac{1}{T} \log \left[ \frac{A}{A - X} \right],$$

in which *K* is the velocity constant, *T* is time and *A* — *X* is the amount remaining at any given time, *T*.

When the reaction is half completed the value of *A* ÷ (*A* — *X*) is always 2, no matter what the original concentration of *A*. The time required to reach this stage of the reaction is inversely proportional to the value of *K*: for it is evident that if we double the value of *K* we must halve the value of *T*, provided the value of *A* ÷ (*A* — *X*) remains 2, or any other constant value. Hence we see that no matter what stage of the reaction we choose (half completed, one fourth completed, etc.) the velocity constants are inversely pro-

<sup>1</sup> Natural logarithms give the true value of *k*, but common logarithms are frequently used: these multiply the value of *k* by .4343. For illustrations of the application of this equation to life processes see Osterhout, W. J. V., SCIENCE, N. S., 39: 544, 1914; *Jour. of Biol. Chem.*, 21: 585, 1917; *Proc. Nat. Acad. Sciences*, 4: 85, 1918.

portional to the times required to bring the reaction to the same stage.

This holds not only for reactions of the first order (where a single substance decomposes) but for reactions of higher orders (where two or more substances combine) as well as for consecutive reactions<sup>2</sup> and autocatalysis.<sup>3</sup>

It follows that when a chemical process proceeds at different rates under different conditions, we can compare the velocity constants by simply taking the reciprocals of the times required to bring the reaction to the same stage. If we merely wish to know the relative rates (as is usually the case in biology) it is not necessary to determine the velocity constants at all.

Whenever the initial conditions are the same with respect to concentration we need only compare the times required for equal amounts of work, since these bring the reaction to the same stage.

If on the other hand one attempts to arrive at the relative rate by comparing the amounts of work performed in equal times (as is frequently done in biological research) he can easily fall into serious error. This is evident from Fig. 1, which shows the curves of a reaction proceeding at two different rates, the velocity constant of *B* being twice as great as that of *A*. It is evident that the abscissa of *A* at any point is just twice that of *B* while no such relation obtains among the ordinates.<sup>4</sup> For example at the point *C* the ordinate of *B* is twice as great as that of *A*, while at the point *D* it is only 1.1 times that of *B*. Hence it is evident that we should compare abscissæ rather than ordinates (*i. e.*, times required to

do equal amounts of work rather than amounts of work performed in equal times).

This principle will also be found to apply to a variety of physical processes.

The principle is sufficiently obvious where successive determinations are made and curves are drawn. But there is a common type of

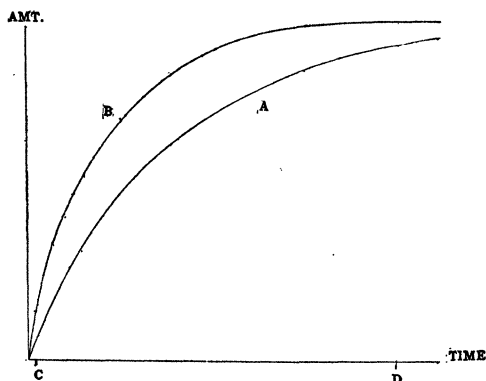


FIG. 1. Curves showing the same process proceeding at different rates one of which, *B*, is twice as rapid as the other, *A*.

experimentation in which, for various reasons, a single observation at one rate is compared with a single observation at another rate. The principle in question is then easily overlooked. In some cases this leads to serious errors.

If we wish to compare the normal rate of a biological process with an abnormal rate (*e. g.*, under the influence of a reagent) it is evident that we can use this principle, but the method of application will depend on circumstances. The normal rate may be constant and its graph a straight line. If this is also true of the abnormal rate it will make no difference whether we compare times or amounts of work.

When the abnormal rate is variable we may have the condition shown in Fig. 2. The normal rate *E* is constant: the variable abnormal rate *F* at any point such as *H* may be determined by drawing the tangent at that point and taking the ratio  $J \div K$ .

In many cases it is not possible to secure data for drawing directly such a curve as that shown in Fig. 2. We may, however, deter-

<sup>2</sup> The principle holds for consecutive reactions in case all the constants are multiplied by the same factor, otherwise not. Cf. Osterhout, W. J. V., *Jour. Biol. Chem.*, 32: 23, 1917

<sup>3</sup> Cf. Mellor, J. W., "Chemical Statics and Dynamics," p. 291, 1909.

<sup>4</sup> We can not avoid the difficulty by comparing the rates of the two processes at a given time; for the rates so obtained will bear no constant ratio to each other. Only when they are compared at the same stage of the reaction will they show a constant relation; this gives the relation between the velocity constants.

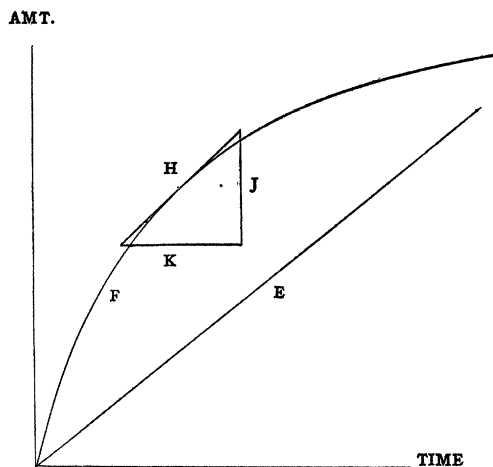


FIG. 2. Curves of a normal biological process *E* proceeding at a constant rate, and the same process under abnormal conditions with a variable rate, *F*.

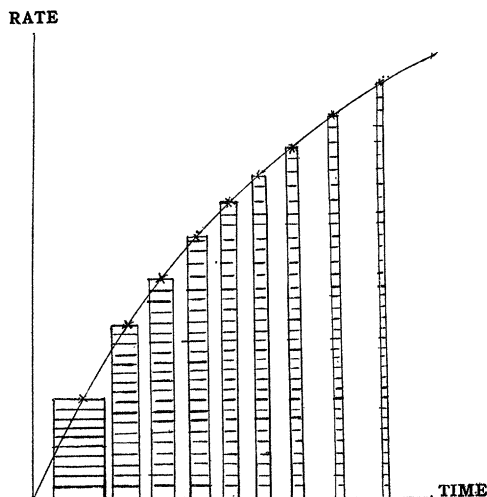


FIG. 3. Curve of a biological process which is studied by measurements of its rate made at frequent intervals. The shaded portions represent periods during which measurements are made. The unshaded portions represent intervals during which there are no measurements.

mine the rate at various periods as shown in Fig. 3, in which the periods during which the rate is measured are shaded while the intervals during which no measurements are made are unshaded.

We can determine the time necessary to

perform a given amount of work and take its reciprocal as the rate: this rate is of course an average for the whole period. If the rate is changing during the period the average rate probably occurs near the middle of the period; hence we may place the ordinate representing the rate in the middle of the period as shown in the figure. The resulting curve can be transformed into a curve of the type shown in Fig. 2 by finding the total amount of work performed at any given time: this is accomplished by finding the area enclosed by the curve and the ordinate of the time chosen (since this area is the product of rate by time, it gives the amount of work performed).

*Summary.*—Measurements of the relative rates of biological processes are frequently made in a faulty manner which may easily be avoided by a slight change of method.

Usually it is preferable to compare the times required to perform a given amount of work (or to bring the reaction to the same stage) rather than to compare the amounts of work performed in a given time.

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#### HOW FOOD AND EXERCISE INCREASE OXIDATION IN THE BODY

LAVOISIER,<sup>1</sup> shortly after his discovery that oxygen supported combustion, showed that physical work increased oxidation in the body, thus giving rise to the energy for the work. He also found that the ingestion of food increased oxidation. Rubner<sup>2</sup> showed that of the food-stuffs, meat increased oxidation most, fat next, and sugar least. The present investigation was begun in an attempt to find out how physical work and the ingestion of food increase oxidation in the body.<sup>3</sup> We had already found that whatever increased oxidation in the body also stimulated the liver to an increased output of catalase, an enzyme

<sup>1</sup> Lavoisier, *Mem. de l'Acad. des Sc.*, 1780.

<sup>2</sup> Rubner, "Energiegesetz," 322.

<sup>3</sup> Burge, Neill and Ashman, *American Journal of Physiology*, Vol. XLV., No. 4, pp. 388-395, 500-506.